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APPLICATION OF ELECTROMAGNETIC FLOW METER

TECHNIQUE IN MAN

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ABSTRACT

In continuation of the work described in the Final
Technical Report, covering the period from 1 June 1961 to
31 May 1962, hemodynamic patterns in man were investigated
by use of the non-cannulating electomagnetic flow meter
technique. Attention was focused on peripheral hemodynamics
in patients with stenotic arterial lesions before and after
surgical correction. In these patients phasic blood flow
and blood pressure distal to the stenosis were recorded
continuously during the course of operation.

Data accumulated in this study show that mean flow rates
and mean blood pressure in these patients — without symptoms
of ischemia during periods of rest — are essentially the
same compared to a group without obstructed lesions. The
stenotic segment expresses itself only as a damping factor,
leading to typical changes in the characteristics of flow
and pressure pattern. Normal patterns were reestablished
approximately five minutes after opening a graft bypass.

Peripheral hemodynamic insufficiencies which occur in
these patients during exercise could be produced experimentally
during the course of operation. The injection of vasodilatory
drugs — prior to the insertion of a bypass graft — into the
artery distal to the stenosis decreased vascular resistance to
flow. Under this condition of increased blood flow demand,

the stenosis became hemodynamically effective. A mean pressure gradient across the stenotic segment could now be demonstrated. The test was repeated after the graft was in place. When resistance to flow was decreased by the same amount, no gradient was detectable.

The effect of mannitol on renal blood flow given during operation was investigated. In all patients studied, an increase in RBF was found. Studies carried out on dogs to evaluate the mechanism which leads to a renal vasodilation indicate that mannitol has no, or at least a very minute, direct effect on the vascular muscles. There is evidence that the precapillary vasodilation is caused by a decrease in wall tension of muscle-type vessels.

INTRODUCTION

During the past decades great advances in direct arterial surgery have been made. The majority of patients so treated have been evaluated as to restoration of circulation by means of direct pressure measurements, restoration of peripheral pulses and by angiography.

It has become evident by the work of a few investigators that an important factor, which evaluates these results, is the change produced in the phasic blood flow rate. To evaluate the changed hemodynamics, it was necessary to study phasic blood flow rates under/conditions. Therefore, the electromagnetic flow meter technique has been used to study the phasic hemodynamic patterns in patients with occlusive vascular disease of the lower extremities before and after surgical correction.

MATERIAL AND METHOD

In a twelve month period the studies reported here were performed at the USAH Munich. Out of a group of 9 patients, 5 served as a control group. The remaining 4 patients underwent reconstructive arterial surgery for occlusive peripheral vascular disease of the lower extremities. Three of these patients underwent insertion of an aortic common femoral bifurcation bypass graft. In the fourth patient, a common femoral to proximal

popliteal bypass graft was placed. All surgery was performed under endotracheal gas oxygen ether anesthesia. Blood flow rates were measured in all patients with the exception of case No. 1 on the superficial femoral artery. In this patient, flow rates were measured in the proximal popliteal artery.

Blood flow rate measurements in the unopened vessel were obtained by means of the sinusoidal electromagnetic flow meter technique. A miniaturized flow meter probe, similar to that developed by Khouri and Gregg (1) was used. The locking device of the flow meter was modified which markedly facilitated placement in the patient. The amplifier used was a Kolin-Kado type, modified by Khouri (2). To establish "0" flow deflection, the vessel was transiently occluded a minimum of 2 cm distal to the point of placement of the probe. The probes were calibrated in vitro on a dissected vessel, perfused by blood, with stop watch and graduate. Calibrations were carried out with constant and intermittent pressure. Intraluminal pressure measurements just proximal to the flow meter were recorded by means of an indwelling needle, connected to a strain gauge. Both flow rate and blood pressure were simultaneously obtained on a direct recorder.

In the control group, all five patients had blood flow rate measured in the superficial femoral artery while undergoing

saphenous vein ligation. Readings were taken in all patients
prior to surgery performed on the venous system and in two cases
readings were repeated after high saphenous ligation and strip-
ping were performed. No evidence of occlusive arterial disease
was present in any patient of this group.

The patients undergoing vascular reconstruction had no
symptoms of ischemia during periods of rest.

RESULTS

In Table 1 are represented the results obtained in members
of the control group. The average mean blood flow in the super-
ficial femoral artery was 121 ml/min with a range of 160 to 95
ml/min. The average maximum blood flow during systole is 454
ml/min with a range between 650 and 315 ml/min. In all but one
case there was a flow rate at the end diastole which was in the
average of 40 ml/min. In three of these patients, significant
back flow was observed in early diastole.

Flow rate patterns obtained in this group of patients
showed wide variations in character as demonstrated in Fig. 1.
This record shows the variability noted in one patient.

In Table II are the results obtained from the four patients
undergoing reconstructive surgery for occlusive arterial disease
of the lower extremity.

Prior to laparotomy and restoration of vascular continuity,
the average mean blood flow rate in the superficial femoral
artery of cases No. 1-3 was 120 ml/min with a range of from 70
to 160 ml/min. This blood flow rate is essentially the same as
in the control group of Table I. However, maximum systolic blood
flow rate is decreased to 277 ml/min compared to 454 of the
control group patients. End diastolic blood flow rate is 23
ml/min. No comparable data from control group patients are
available concerning the measurements of flow rate in the popli-
teal artery, performed in patient No. 4.

After bypassing the stenotic segment with an arterial graft
the mean blood flow rate in the superficial femoral artery was
150 ml/min on the average. There was no significant difference
in the mean blood flow in cases 1, 2, and 4 after the graft was
opened. In case No. 3, the increase in the mean blood flow rate
was more than twofold. There was a uniform change, however, in
the characteristics of phasic blood flow patterns after bypass
grafts were inserted in all four cases, a fact which is also
illustrated in Fig. 2. Maximum systolic blood flow on the
average is increased approximately twofold. End diastolic blood
flow rate decreased in all but one patient. Mean intravascular
blood pressure taken at the site of flow measurement was essen-
tially the same before and after bypassing the stenotic segment.

Pressure amplitude, however, was increased after the surgical correction.

A mean pressure gradient across the occluded vesse`. segment prior to bypassing could only be demonstrated in those patients after intraarterial injection of a dilating substance when blood flow rate was increased. In case No. 3, after the injection of 40 mg Papaverin Hydrochloride into the superficial femoral artery, decreasing the resistance to flow from 1.63 to 0.68 $\frac{mmHg \cdot min}{ml}$, a mean pressure gradient of 30 mmHg (aorta 114, superficial femoral artery 84 mmHg) across the occlusive area was then demonstrated. After insertion $\overset{of}{/}$ the bypass graft, the resistance to flow decreased to the same degree — during the hyperemic phase after release of the clamps — but then no pressure gradient from aorta to superficial femoral artery was present.

Intravascular Pressure Patterns

Prior to bypassing, an aortofemoral mean pressure gradient across the occluded vessel could not be demonstrated in these patients, although the pressure amplitude was decreased distally to the stenosis. Therefore a gradient was eliminated after insertion of the graft. At the same time pressure amplitude in the femoral artery equalled that in the aorta.

DISCUSSION

1. Hemodynamics noted in a control and disease group.
Under basal conditions of general anesthesia in which all patients

were studied, it was surprising to find that mean blood flow rate in the superficial femoral artery of normal patients and in those with vascular occlusive disease in the aorta and iliac artery were essentially the same.

It is further noted that in 3 of the 4 cases in the group with disease, mean blood flow rate in the superficial femoral artery did not increase above control values following a corrective bypass procedure. In the absence of gangrene and rest pain, these findings supported preoperative clinical impressions that existing flow rates were adequate under conditions of rest.

Under basal conditions of surgery upon the diseased patient, the only gradient demonstrated between aorta and superficial femoral artery is that of maximum systolic pressure. Mean pressure, however, is the same on either side of the obstruction. Flow through the stenotic segment and associated collateral channels produced a mean pressure distal to the obstruction, which was equal to that found in the aorta. These findings would indicate that the occluded segment acts as a damping factor rather than an effective resistance to flow under rest conditions. The occluded segment demonstrates its effective resistance when the peripheral arterial tree is dilated, then an aortofemoral mean pressure gradient is present. This situation normally occurs during exercise and can be provoked during the course of surgery by the injection of a dilating drug in the femoral artery. An exact measurement of phasic pressure patterns in small arteries

is difficult to obtain. Artefacts caused by the size of needle
bore, intraluminal needle position, and polyethylene tubing
distort systolic pressure patterns. It is suggested that mean
pressure values in the presence of a dilated peripheral vascular
bed give more accurate information concerning the stenotic effect.

The resistance to flow caused by the stenotic segment cannot
be calculated from the measured pressure gradient and blood flow
rate during vasodilation. This would be possible if all blood
passing the site of measurement also passed through the area of
stenosis. The presence of collateral vessels (demonstrated by
arteriography) precludes this possibility since it is obvious
that only a portion of measured blood flow rate in the superficial
femoral artery has passed through the occluded segment.

2. Variability of flow patterns in control and disease group.

In the control group we could not demonstrate a specific type of
flow pattern in the superficial femoral artery, although they differ
from those of the disease group (Fig. 1). This normal variability
is natural, since head pressure pattern, vessel elasticity and
diameter, and peripheral resistance to flow which all contribute
to the flow pattern are varying factors. The magnitude of re-
flected pulse pressure waves especially, with its marked effect
on early diastolic back flow, depends mostly on peripheral vessel
tonus. Therefore, back flow during early diastole was not a con-
stant finding although in more than half of our measurements it
occurred. But the sharp rise in flow in the beginning of systole

with an abrupt fall during end of systole and early diastole
was an invariable finding in the control group.

Flow pattern in patients with obstructed arteries differ
from those of the control group mainly in systolic maximum and
during diastole (Fig. 2). There was a slow fall from the maximum
systolic flow rate, and early diastolic back flow never occurred.
These changes are closely related to the diminished reflected
pressure waves under these conditions. The amplitude of the
reflected pressure wave depends on the wave resistance (R_W)
which is a linear function of wave velocity (C) and is inversely
proportional to cross sectional area (A): $R_W = \frac{C}{A}$. In case of
arterial obstructions proximal to the site of measurement, wave
velocity is diminished which results in a decreased wave resistance
and subsequently in a decreased amplitude of reflected pressure
waves. This leads to a diminished systolic pressure maximum and
disappearance of pressure undulations superimposed on the funda-
mental pressure contour. This is in agreement with the above
findings of a blood flow pattern during diastole in these patients
which show slight undulations and never a back flow in diastole.
Similar characteristics of diastolic flow pattern — although at
a higher level — were obtained during the injection of vaso-
dilating drugs when cross sectional vessel area was increased.
(Fig. 3). According to the above equation, this also leads to a
decrease in wave resistance (R_W) with a resulting diminished
amplitude of reflected pressure wave.

SECOND PART

THE EFFECT OF MANNITOL ON RENAL BLOOD FLOW DURING SURGERY

In two patients undergoing abdominal surgery for vascular corrections, blood flow rate in one renal artery was measured at the end of operation, before and after 12.5 gm mannitol i.v. In both cases an increase in RBF was found

To evaluate the mechanism which leads to an increase in RBF under the influence of mannitol, dog experiments were carried out. Renal blood flow (RBF) in aneethetized dogs was measured by the non-cannulating electromagnetic flow meter technique. Intrarenal tissue pressure (TP) was obtained by a conical 28 gauge needle inserted into cortical tissue and connected to a strain gauge. Intrarenal venous pressure (IVP) was measured via a PVC catheter, threaded through the spermatical or ovarian vein into the interlobar vein. BP was measured via a femoral artery catheter. All parameters were recorded on a direct recording system.

In all experiments, an increase in RBF, BP, and IVP was observed. It could be demonstrated that vasodilation, which occurred, is not caused by mannitol per se. Fig. 4 is representa- tive for experiments in which ureteral occlusion (stop flow) was applied during mannitol diuresis and at a constant blood mannitol level. RBF increases from 4.9 ml/gm·min during free flow mannitol diuresis to 7.6 ml/gm·min at the end of the stop

flow period. The increase in TP caused by the accumulation of intratubular mannitol, poorly reabsorbed by the tubular membranes, is of the same order as that of IVP and ureteral pressure. The increase in IVP demonstrates a compression of veins at the intrarenal and extrarenal border. Because of this increase in intrarenal venous resistance, precapillary vessels must dilate to a degree that a net decrease in total resistance can come about.

According to the Laplace equation, tangential wall tension of precapillary vessels can be calculated under these circumstances. In all experiments, an inverse correlation between RBF and tangential wall tension was found. It is therefore suggested that the decrease in precapillary resistance to flow is due to a relaxation of vascular muscles. This relaxation is a result of a reduced stretch stimulus when tangential wall tension is lowered.

A part of the next year's work will therefore be to investigate this phenomenon in more detail by variations of the experimental approach. Up to yet it is already demonstrated that mannitol per se is not the factor responsible for an increase in renal blood flow.

Literature: (1) Kolin,A. and R.T.Kado
           Proc. Natl. Acad. Sci. 45, 1312 (1959)

           (2) Khouri,E. and D.E.Gregg
           J. Appl. Physiol. 18, 224 (1963)

TABLE 1

NORMALS: BLOOD FLOW (ML/MIN) IN SUPERFICIAL FEMORAL ARTERY

Case	Mean	Maximum Systole	End of Diastole	Early Diastole
1	140	650	5	-40
2	140	420	20	-25
	160^x	480^x	28^x	0^x
3	115	520	18	0
4	95	315	20	-35
5	105	405	15	0
	95^x	390^x	0^x	0
MEAN	121	454	14	

x Reading after high saphenous ligation and stripping.

TABLE 2

PERIPHERAL HEMODYNAMICS IN PATIENTS WITH ARTERIAL

OCCLUSIVE DISEASE BEFORE AND AFTER SURGICAL CORRECTION

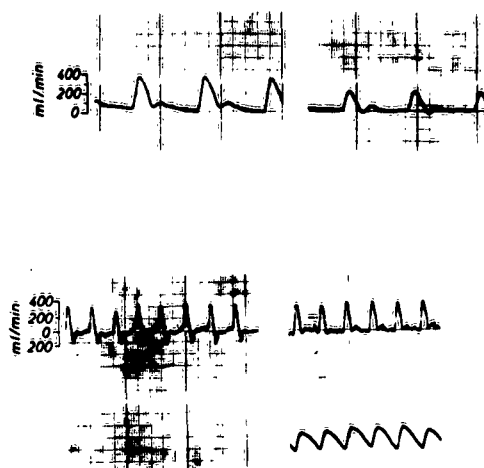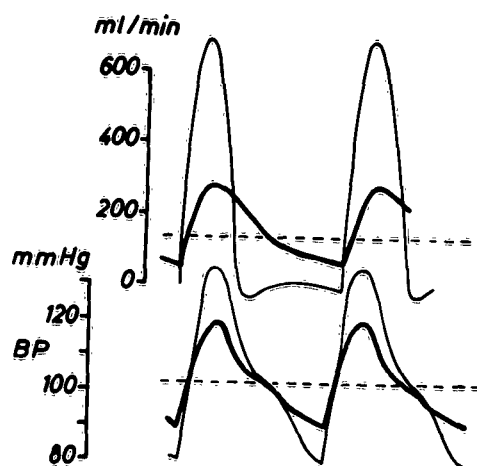| CASE	BLOOD FLOW (ML/MIN)								BP (mmHg)	
	Mean		Maximum Systolic		End of Diastole		Early Diastole			
	Before	After	Before	After	Before	After	Before	After	Before	After
1	160	145	315	515	30	10			90	90
2	130	145	300	600	10	10		-50	105 (120-90)	100 (135-80)
3	70	160	140	300	30	12			105 (135-85)	145-86
MEAN	120	150	277	472	23					
4	115	135	280	680	50	0		-15		A. Popliteal

Fig. 1

Fig. 2

Fig 1) Variations of bleed flow pattern in the superficial femoral
artery of man without arterial obstructive disease.

Fig 2) Phasic pattern of blood flow and blood pressure in the super-
ficial femoral artery of patients with a stenosis of the iliac
artery (thick line) and after insertion of a bypass (thin line).
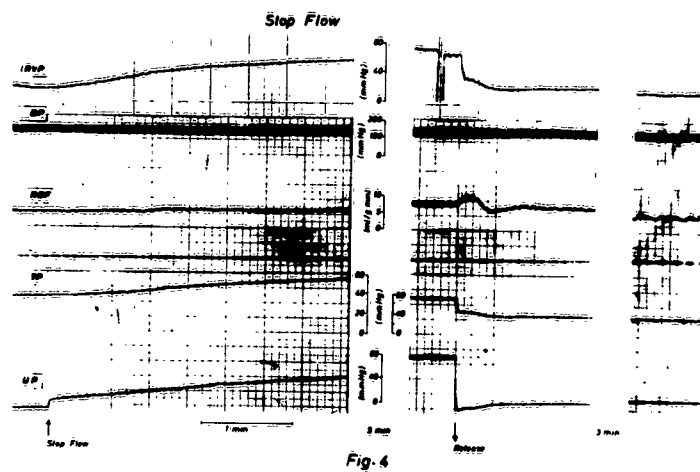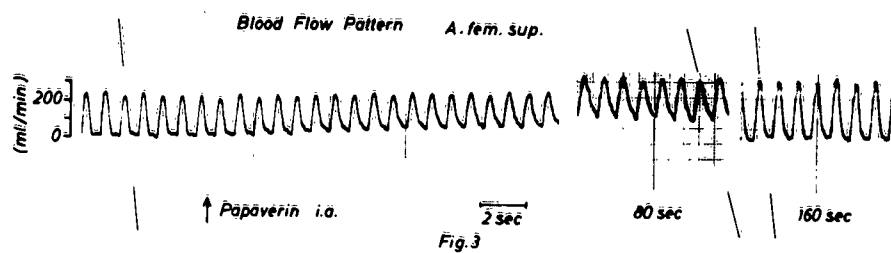
Fig. 3

Fig. 4

Fig 3) The effect of papaverine on blood flow pattern in the superficial
femoral artery of man.

Fig 4) Renal blood flow (RBF), intrarenal venous pressure (IRVP), renal
tissue pressure (TP), and ureteral pressure (UP) in the dog kidney
in situ during stop flow in osmotic diuresis and after its release.

D. Personnel:

Principal Investigator:	Dr. Klaus Thurau
Assistant Investigator:	Dr. Peter Deetjen
Assistant Investigator:	Dr. Günter Henne
Mechanic:	Manfred Sembach
Electronic Engineer:	Lothar Heinich
Technical Assistant:	Ursula Voszhag

There have been no changes in research policies.

E. Approximately 4700 man hours were expended, and a total
of approximately 15,000 DM for materials were spent.
No new property has been acquired during the contract
period.